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RESEARCH RESULTS

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VENTILATION DESIGN AND PROCEDURES FOR PASSENGER RAIL

SUMMARY

The Federal Railroad Administration (FRA) sponsored research by the John A. Volpe National Transportation Systems Center (Volpe Center) to study the principles of fire growth and smoke management, as well as the current state of standards and regulation in the US and abroad. This study was in response to the American Public Transportation Association's (APTA) Rail Safety Advisory Committee's Fire Safety Working Group inquiry into the use of ventilation onboard passenger rail in the event of a fire-related emergency. Researchers consulted industry members to gain insight into the challenges with modeling and use of active ventilation in a fire emergency.

BACKGROUND

Guidelines and standards for the design and operation of powered ventilation onboard passenger rail can vary between both international regulatory organizations and within the US. To date there exists little information as to how these requirements were decided and the principles behind them. Investigating these principles may inform FRA and institutions such as APTA in the use of Fire Safety Analysis in general and hazard modeling.

OBJECTIVES

The objective of this study was to provide insight into the motivations for ventilation system design and operation in a fire emergency by examining fire growth modeling and flame spread, as well as speaking with members of the industry.

METHODS

This research was conducted in two parts. First, the team worked to gain an understanding of the theory behind fire and smoke modeling in a train compartment. This was followed by interviews with industry members to gain insight on major design considerations and operation policies. The team conducted interviews with members of Hatch, LTK, Underground Command Safety LLC, and Los Angeles Metro.

RESULTS

Principles of Fire Growth and Smoke Movement

While there are multiple metrics to measure the size and danger presented by a fire, it is generally accepted that heat release rate is the most important (Babrauskas & Peacock, 1991). Fire growth modeling on passenger rail makes use of design fires that follow particular heat-release rate curves that feature four distinct regimes: initiation to sustained ignition, growth, steady burning, and decay (see Figure 1). Fire growth typically follows a "t-squared growth" curve, where the heat release-versus-time graph resembles the right side of a parabola during the growth phase. It is also generally accepted that decay follows a similar curve and is applied to most design fires (Peacock, Reneke, Averill, Bukowski, & Klote, 2002). The size and heat-release rate of a steady burning fire can be determined by availability of fuel or oxygen flow. Steady burning in small compartments can exhibit a "flashover" phenomenon in which the energy feedback from the fire's surroundings leads to a rapid spread of fire to all combustibles in a compartment.

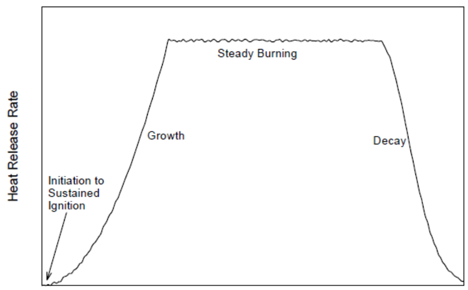

Figure 1*: Four Distinct Fire Regimes (Babrauskas & Peacock, 1991)*

Influence of Passive Ventilation
The degree to which passive ventilation, such as opening windows or vents, can influence a fire may also be modeled in terms of heat release rate. An often-used predictive model describing the influence of ventilation in a compartment fire is based on oxygen consumption, using Huggett's oxygen consumption theory of the form

$$\dot{Q} = E\left[\frac{MJ}{kg}\right]\dot{m}_o[\frac{kg}{s}]$$

where $\dot{m}_o$ is the oxygen consumption rate and E is a proportionality coefficient, usually accepted as 13.1 $\frac{MJ}{kg}$ (Huggett, 1980).

As seen in Figure 2, a mass flowrate balance can be performed given $\dot{m}_g$, ρ_g, ρ_a, and $\dot{m}_a$, the mass flowrates, and densities of hot gasses leaving the car and air entering the car, respectively, along with the height of the window opening.

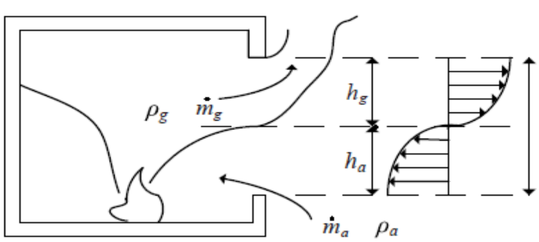

Figure 2: Buoyant flows across the vent of a compartment fire.

This yields a model of:

$$\dot{Q}_{flashover} = 1606 \times Window\ Area\ Opening \times Square\ Root\ of\ Height\ of\ Window\ Opening,$$

with the dimensions of the window opening being known as the "ventilation factor." This oxygen-consumption-based predictive model has been demonstrated to be more accurate than energy-balance-based predictive models when compared to computer-based numerical simulations (Peacock, Reneke, Averill, Bukowski, & Klote, 2002), and it is considered to be a reliable predictor.

Current Standards Regarding the Use of Ventilation Onboard Passenger Rail
In general, regulatory standards in the US are either non-prescriptive or simply require immediate shutdown of all ventilation systems.

US Regulatory and Industrial Standards
FRA CFR 49 § 238.103 part (C) requires a fire safety analysis that "reasonably ensures that a ventilation system does not contribute to the lethality of a fire" (49 CFR Part 238 Passenger Equipment Safety Standards), whereas National Fire Protection Association (NFPA) 130 Chapter 8 "Vehicles" requires vehicles to "have provisions to deactivate all ventilation systems manually or automatically" (NFPA 130: Standard For Fixed Guideway Transit and Passenger Rail Systems, 2020). Additionally, in the event of a fire, Amtrak Service Standards require operators to turn off the blower system "so that smoke will not circulate to other parts of the car" (Amtrak Corporation, 2022).

International Standards
International standards contain similar requirements to shut down ventilation units. The European EN 45545-6 requires this for most design and operational categories, and further explains that "…control of ventilation is intended to limit the rate at which the products of fire move to and through passenger areas and staff areas." (EN 45545 (Parts 1 through 7) - Railway Applications - Fire Protection on Railway Vehicles, 2013). Japan requires that forced ventilation devices have the capacity that is

twice the rated passenger capacity, based on a volume of 13 $\frac{m^3}{person \times hour}$. The forced ventilation should not contribute to the flow of fire and smoke throughout the cabins. (Ministry of Land, Infrastructure, Tourism, 2012)

Active Ventilation Experiments and Modeling
Limited research has emerged regarding the effectiveness of active smoke exhaust onboard passenger trains or similar passenger vehicles (e.g., busses or airplanes). One notable example by Lázaro, Lázaro, Cortabarria, & Alvear (2020) demonstrated the potential use of exhaust fans as a method of meeting the same performance goals of fire-barriers that are typically required in certain design categories of European passenger cars. Shown in Figure 3, the design featured two blowers at the top of the car that were able to sustain tenability requirements for adjacent cars by preventing smoke and other products from traveling between junctions (Lázaro et al., 2020).

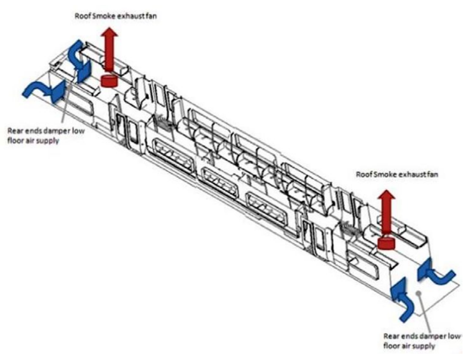

Figure 3: Diagram of Roof Exhaust Fan Installation

Interviews With Industry Personnel
Interviews were conducted with members of LA Metro, Hatch LTK, and Gary English from Underground Command Safety LLC, who previously served as the deputy fire safety chief of major transportation projects in Seattle, WA. The consensus from these interviewees was that powered ventilation is generally not used in the United States as a means of fire mitigation nor as a method of preventing fire and/or smoke from spreading between cars. This is due to the many variables in a real fire situation that make the effect of a ventilation system highly unreliable – if designers or operators are not careful with the use of ventilation, it could exacerbate the problem. The main concern stems from the impact that fresh air can have on a fire from circulated ventilation – the benefits of exhausting smoke and hot gasses *out of* a car may be outweighed by the increased fire growth hazard by introducing more fresh air *into* the car. Of additional concern is the danger that exhausted hot gasses and smoke can pose to passengers in underground operations (e.g., in a tunnel or at a train station). Comfort HVAC systems are typically required to be powered down in the case of a fire emergency for the same reason.

CONCLUSIONS

The research team studied the principles of fire growth and smoke management and the current state of standards and regulation in the US and abroad, including interviews with industry members. The team found that although research has demonstrated a dependable understanding of heat release rate and fire dynamics modeling, the impact of active ventilation upon a fire's development is widely unknown. Because of this low degree of predictability and the potential to exacerbate a fire emergency by use of active ventilation, most design standards and operation standards require powered ventilation systems to be shut down in the case of fire. Limited experiments have demonstrated the ability to exhaust smoke to achieve the same performance of fire barriers, though their impact in real operation scenarios remains unknown.

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